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TITLE:

***REDUCTION OF ELECTROMAGNETIC INTERFERENCE IN INTEGRATED
CIRCUIT DEVICE PACKAGES***

SPECIFICATION

TECHNICAL FIELD

The present invention relates generally to reduction of electromagnetic interference and specifically to reduction of electromagnetic interference generated within an integrated circuit device package.

BACKGROUND OF THE INVENTION

Advances in the performance of microcomputer based electronics have resulted in dramatic increases in operating speeds of the logic switching circuits. Increased switching and operating speeds correspond to increased bandwidths of the electronic signals transmitted within the interior of an electronic device which become a significant source for electromagnetic radiation causing interference with the internal circuitry of the device itself and with other electronic devices operating within the vicinity of the device. The electromagnetic radiation emitted at these higher frequencies may cause undesirable electromagnetic coupling between data paths resulting in cross channel interference.

The amount of internally generated electromagnetic radiation must be

limited to the guidelines and regulations set by governmental agencies such as the FCC in the United States and CISPR in European countries. Sources of electromagnetic radiation originating externally to the device may also affect and interfere with the operation of the device. In general the problems resulting from unwanted electromagnetic radiation are classified as electromagnetic interference (EMI).

A recurring observation in the analysis of EMI performance in products that use VLSI integrated circuits is that there is a significant amount of emission radiated directly from the integrated circuit package itself before the signal connections from the device are available on an external pin. This is particularly evident in devices that have a large number of pins, such as a common 208 pin Quad Flat Pack (QFP) device. A 208 pin QFP device is typically on the order of 1 inch square with the actual integrated circuit itself occupying only a small amount of the real estate of the QFP package. Typically, the integrated circuit (IC) is relatively small being on the order of 0.2 square inches to 0.3 square inches. As a result, there must be internal conductor leads from the IC silicon wafer to the external pins of the device. This is typically implemented with a lead frame of metal strips etched or stamped from a sheet of material to support the integrated circuit chip and to provide a signal path for the input and output (I/O) pins of the QFP device.

In such a design there may be a significant conductor length from the IC itself through the bonding wires and the lead frame conductors to the external pins of the device. This is especially true for pins at or near the corner of the device, in which case the conductor lead length may be well over 0.5 inch.

The described physical lead lengths in typical integrated circuit packaging designs generally cause two problems. The first problem is mid and high frequency signal degradation introduced by the inherent series inductance of the conductor leads which is particularly a problem for the power and ground feeds. The second problem is that the conductor leads may radiate EMI energy as an antenna thereby interfering with the signals on adjacent conductor leads in the

package and with other signal paths and components in the electronic device in which the integrated circuit is utilized. The techniques known in the art for reducing electromagnetic interference are effective only external to the integrated circuit device package. Thus, there lies a need for a method and apparatus to reduce or eliminate electromagnetic radiation internal to the integrated circuit device package itself.

SUMMARY OF THE INVENTION

The present invention provides reduction and elimination of electromagnetic radiation in an integrated circuit. The electromagnetic radiation is reduced or eliminated, and electrical signals internal to the integrated circuit package are conditioned internally within the integrated circuit package itself.

BRIEF DESCRIPTION OF THE DRAWINGS

The numerous objects and advantages of the present invention may be better understood by those skilled in the art by reference to the accompanying figures in which:

FIG. 1 is a somewhat diagrammatic representation of the internal design of a typical integrated circuit package;

FIG. 2 is a schematic illustration of the electrical model of a typical integrated circuit device package;

FIG. 3 is a somewhat schematic illustration of the electrical model of an integrated circuit device package utilizing the present invention;

FIG. 4 illustrates the resulting characteristic curve of the electrical signals conditioned by the present invention;

FIG. 5 is a schematic elevation view of an integrated circuit device package of the present invention illustrating the magnetic flux pattern occurring therein;

FIG. 6 is a somewhat diagrammatic representation of the internal design of an integrated circuit device package utilizing the present invention;

FIG. 7 is a schematic elevation view of an integrated circuit device package of a preferred embodiment of the present invention illustrating the magnetic flux pattern occurring therein;

FIG. 8 is a somewhat diagrammatic representation of the internal design of an integrated circuit device package utilizing a preferred embodiment of the present invention; and

FIG. 9 is an electrical schematic diagram of the equivalent circuit model of a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF AN EXEMPLARY EMBODIMENT

FIG. 1 illustrates the model of a typical Quad Flat Pack (QFP) integrated circuit device. The Quad Flat Pack may comprise a 1.0 inch square integrated circuit device package 10. The integrated circuit (IC) 12 itself may only comprise a 0.2 inch square or 0.3 inch square wafer of silicon containing the actual integrated circuitry of the integrated circuit package 10. The device package 10 is formed by encapsulating the integrated circuit 12 in a plastic medium 14 which defines the physical dimensions of the device package 10. The plastic medium 14 protects and supports the integrated circuit 12 and contains the lead conductors which electrically connect the IC 12 to the external input/output (I/O) pins 18 of the device package 10. The lead frame conductors 16 connect to the IC 12 via bonding wires 20 which directly connect to strategic circuitry nodes on the IC 12.

FIG. 2 illustrates the electrical model of the typical integrated circuit package of FIG. 1. FIG. 2 illustrates how the conductor leads 16 from the I/O pins 18 to the integrated circuit 12 are not ideal transmission lines but in practice exhibit a per length series inductance. Longer lengths of the conductor leads 16 result in larger values of the inherent series inductance. Input leads 16 connect the I/O pins 18 to input buffers 22 on the integrated circuit 12, and output leads 16 connect the I/O pins 18 to output buffers on the integrated circuit 12. In general, the input and output conductor leads 16 exhibit input series inductance L_{IN} and output series inductance L_{OUT} .

Ideally, the inductance of the V_{CC} and V_{GND} leads would be zero henries. In a preferred embodiment of the present invention the effective inductance of the V_{CC} and V_{GND} rails is effectively reduced with multiple parallel branches since there are typically multiple V_{CC} and V_{GND} pins in a given integrated circuit device package 10. Utilization of multiple signal paths to reduce the effective inductance of a data signal path 16 is not feasible; therefore the effective series inductances L_{IN} and L_{OUT} of the lead conductors 16 preferably exhibit a small amount of "lossy" inductance. By making the series inductance of the conductor leads 16 lossy, the detrimental EMI effects of the series inductances may be thereby reduced.

Given the construction of the lead frame 16, the packaging function for the integrated circuit 12 is preferably completed by placing the lead frame 16 with bonded integrated circuit 12 into a injection molding cavity where molten plastic is injected to encapsulate the lead frame 16 and integrated circuit 12 to form the device package 10. The plastic material 14 is preferably electrically passive and electrically non-conducting so that it will cause no degradation of the electrical signals to and from the integrated circuit 12.

In a preferred embodiment of the present invention a modeled plastic material 14 having desired electromagnetic properties to advantageously affect the signals to and from the integrated circuit 12 as the signals are routed through the lead frame 16 of the device is utilized. A small amount of ferrite powder is preferably blended with the plastic material 14 to achieve the slightly lossy magnetic characteristic of the encapsulating plastic medium 14 surrounding the lead frame conductors 16. Ferrite is preferred because of its high resistivity and permeability.

FIG. 3 illustrates the effects of the introduction of ferrite powder into the encapsulating plastic of the integrated circuit device package of FIG. 1. The introduction of a ferrite material into the encapsulating plastic 14 alters the permeance of the encapsulating medium 14 and thereby affects the electrical characteristics of the inherent series impedance of the lead conductors 16. The

ferrite material in the encapsulating medium 14 causes the series inductance of the lead conductors 16A and 16B to behave as a lossy inductor L_F . Further, the ferrite material contributes to the mutual inductance M_F and resulting coupling primarily associated with adjacent leads 16A and 16B. The ferrite material exhibits hysteresis loss, but because ferrite has high characteristic resistivity, it exhibits no eddy-current loss. Increasing the permeance of the physical medium 14 surrounding the inductance with the presence of a magnetic material such as ferrite produces an effect opposite to the effect resulting with magnetic core inductors; instead of concentrating the magnetic flux within the center of the inductor to thereby augment the effective inductance as with a magnetic core, the increased permeance of the surrounding medium 14 due to the magnetic material tends to distribute the flux throughout the medium away from the inductor thereby attenuating the effective inductance.

FIG. 4 illustrates the resulting preferred characteristic signal shape of a given data signal when a ferrite material is introduced into the encapsulating medium. The lossy inductor L_F as shown in FIG. 3 would serve to attenuate only the highest frequency signal components while introducing generally little true inductance effects of overshoot and ringing associated with the series inductance of the leads 16 when no ferrite is present. The Q of the inherent series inductance of the conductor leads 16 is thereby minimized rather than maximized. Thus, the intentionally introduced inductor loss reduces the undesired effects of the inherent series inductance such as overshoot and ringing.

FIG. 5 illustrates a two conductor mutual coupling model of the present invention. Introduction of mutual coupling and signal crosstalk between two adjacent lead conductors 16A and 16B would be an undesirable effect that is preferably minimized. Current flowing into conductor 16A introduces magnetic flux 32 through adjacent conductor 16B thereby inducing a current therein. In a preferred embodiment of the present invention a relatively small amount of ferrite material is blended in the encapsulating plastic 14 resulting in a relative

permeability of the surrounding material 14 that is not too high to cause significant mutual coupling but yet sufficient to desirably affect the series inductance of the lead conductors 16. In a preferred embodiment of the present invention, the relative permittivity of the encapsulating medium 14 ranges from 5 to 10.

Regarding the two conductor mutual coupling example as shown in FIG. 3, the actual amount of mutual inductance M_F between two adjacent lead conductors 16A and 16B is small with respect to the self-inductance L_F of each conductor 16. In a preferred embodiment of the present invention, the reduction of crosstalk on any particular conductor 16 may be further achieved by placing that particular lead conductor 16 adjacent to a V_{CC} or V_{GND} lead to avoid any coupling to another data signal path.

FIG. 6 illustrates a preferred embodiment of the present invention in which mutual coupling between adjacent leads is eliminated. The virtual elimination of the mutual inductance may be achieved by molding the device package 10 in two steps. The first step preferably comprises constructing the lead frame 16 and then forming or molding individual ferrite "microbeads" 30 on each lead 16. The microbeads 30 are preferably offset so they do not interfere with adjacent microbeads 30. The microbeads 30 are electrically isolated from the adjacent conductors 16.

In a preferred embodiment of the present invention the microbeads 30 are made of pure ferrite material which may be constructed using known ceramic techniques, and the microbeads 30 would be formed as an integral part of the lead frame 16. The microbeads 30 are utilized in a manner analogous to the utilization of ferrite bead chokes in radio-frequency transmission lines and antennas. The bead surrounds the transmission line and effectively chokes undesired high frequency signals immediately external to the transmission line that are the source of electromagnetic interference without affecting data signals passing therethrough.

The second step preferably comprises ordinary plastic encapsulation of the frame 16 and the integrated circuit 12 upon completion of the bonding and wiring of the IC 12 to the lead frame 16. In an alternative embodiment of the present invention the inclusion of a ferrite microbead 30 on any given lead 16 is optional depending upon the type of signal transmitted thereon. For example, V_{CC} and V_{GND} signals perform better if there is no ferrite bead 30 on those leads. In a preferred embodiment, the standard lead frame 16 is constructed with a microbead 30 on each lead 16. Microbeads 16 may be selectively removed by crushing away the undesired beads 30 which is facilitated by the inherent brittleness of ferrite. Preferably, a simple press may be utilized having small crushing pins arranged above the corresponding microbeads to be crushed in which all undesired microbeads 30 may be removed in a single step.

FIG. 7 illustrates a preferred embodiment of the present invention in which the magnetic flux is contained within the ferrite beads. The ferrite bead 30 surrounding conductor lead 16A completely contains the magnetic flux 32 generated by the current flowing into conductor lead 16A. Thus, no current is induced in conductor lead 16B from the magnetic flux 32 created by the current flowing through conductor lead 16A. In a preferred embodiment of the present invention, only the microbeads 30 contain ferrite wherein the encapsulating medium 14 entirely comprises non-magnetic plastic. Alternatively, a small amount of ferrite may be blended in with the encapsulating plastic 14 in conjunction with the utilization of ferrite beads to further achieve the reduction of electromagnetic interference.

FIG. 8 illustrates the preferred placement of the ferrite beads of the present invention relative to the integrated circuit wafer in the device package. The most effective physical location for the microbeads 30 is as near to the integrated circuit 12 as possible. With the required close spacing of the lead frame conductors 16 near the IC bonding pads 20, the physical size of a microbead 30 may not be very large. However the effects of the reduced size are

offset by the fact that the placement of the ferrite microbead 30 near the IC 12 is nearly ideal.

FIG. 9 illustrates the resulting electrical circuit model of a given conductor path in an integrated circuit device package of the present invention. An output signal V_{OUT} from the integrated circuit 12 feeds into an output buffer 24 which is externally connected through an IC bonding wire pad 20. The bonding wire 20 exhibits a small series inductance L_B which is small relative to the inductance L_F of the ferrite microbead 30. The lead frame conductor 16 exhibits a characteristic lumped series inductance L_{OUT} and shunt capacitance C_{OUT} , the effects of which are negligible compared to the inductance L_F of the microbead 30, and extends through the encapsulating medium 14. The effects of inductance L_{OUT} and capacitance C_{OUT} may be further reduced by the blending of ferrite with the encapsulation material 14. The lead frame conductor 16 connects to an external pin 18 on the exterior of the device package 10.

In view of the above detailed description of a preferred embodiment and modifications thereof, various other modifications will now become apparent to those skilled in the art. The contemplation of the invention below encompasses the disclosed embodiments and all reasonable modifications and variations without departing from the spirit and scope of the invention.